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INCREASING LIFT BY RELEASING COMPRESSED AIR ON SUCTION SIDE OF AIRFOIL

By F. Seewald

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Some time ago an investigation was conducted by the D.V.L. (Deutsche Versuchsanstalt für Luftfahrt) on the same subject treated by K. Wieland in the preceding article ("Untersuchungen an einem neuartigen Dusenflugel," Zeitschrift für Flugtechnik und Motorluftschiffahrt, August 16, 1927, pp. 346-350). Since the results of that investigation afford a somewhat more extensive view than those obtained by Mr. Wieland, it will be briefly described here. First, a few fundamental considerations on the nature of the flow with such an airfoil will be mentioned.

In investigating many kinds of flow, advantageous use can be made of the conception of the ideal fluid, i.e., of a fluid which is not compressible and which offers no resistance to change in form. In general, fluids offer very little resistance to a slow change in form. The more quickly, however, the form of a fluid is changed, that is, the greater the relative velocity between two neighboring molecules, the more noticeable is the resistance due to the internal friction or viscosity in all natural fluids. This fact warrants the conclusion that, in any

*"Die Erhohung des Auftriebs durch Ausblasen von Druckluft an der Saugseite eines Tragflügels." From "Zeitschrift für Flugtechnik und Motorluftschiffahrt," August 16, 1927, pp. 350-353.

process of flow, the effect of viscosity is slight in all regions where the relative velocity varies but slightly in two neighboring lines of flow for, in such regions, the fluid molecules belonging to adjacent lines of flow pass one another only at low velocities. For this reason the flow in such a region conforms sufficiently to the theory of the ideal fluid.

The case is different, however, in those regions of a flow where the velocities differ greatly in adjacent streamlines. This is the case near the surface of an object being towed through a fluid. Experience teaches us that the molecules of a fluid, which come in immediate contact with the object, adhere to it. Even at a little distance from the surface the fluid molecules have a velocity of the order of magnitude of the velocity of the object itself. There is, therefore, a decided difference in the velocity near the surface and in this region the viscosity plays an important part. In 1904, Prandtl called attention to the importance of the phenomena in this region, which is now called the "boundary layer."*

The circulation around an airfoil can be explained only with the aid of the conception of the internal friction or viscosity of a fluid. When an airfoil is towed through a fluid, there is no circulation at first. If the fluid had no viscosity, no cir-

*Prandtl, L., "Ueber Flussigkeitsbewegung bei sehr kleiner Reibung," originally published in 1904 and republished in 1927 by the press of the Göttingen "Kaiser Wilhelm Institute for Flow Research." This question has also been discussed by A. Betz, "Wirbelschichten und ihre Bedeutung für die Stromungsubergänge" in "Die Naturwissenschaften," 1926, p. 1228.

culation could develop. An infinitely great velocity, however, would then develop in the flow around the trailing edge. Practically, this means that the velocity would have to be very great in the immediate vicinity of the trailing edge, to which the fluid particles, which come into immediate contact with the surface, adhere. At this point there is, therefore, an especially great difference in the velocity of the neighboring streamlines. This makes the internal friction of the fluid especially noticeable and develops a resistance to the flow around the trailing edge. The effect of this is to develop an eddy or vortex on the trailing edge. The mass of fluid embraced by the vortex increases in size, until the whole vortex mass is swept away by the rest of the fluid. In this way the whole flow is so controlled as to produce the smoothest possible flow at the trailing edge. In order to render this possible, the velocity must be increased on the suction or negative-pressure side of the airfoil and reduced on the pressure side. This phenomenon is designated as the circulation.

Friction is developed at all points of the surface, although its effect is greatest at the trailing edge. On the pressure side of the airfoil, vortices are produced which rotate in the same direction as the vortices at the trailing edge. They accordingly help to develop and maintain the circulation. On the suction side, however, vortices are developed which rotate in the opposite direction and consequently weaken the circulation. The vortices on the suction side are the stronger ones, however, since the velocities are greater there and the friction is consequently greater. Hence the circulation, developed by the vortices passing off the trailing edge, is again weakened. With a weaker circulation, however, a flow is developed around the trailing edge and the circulation is again strengthened. Hence, it is obvious that there must be a constant flow around the trailing edge and indeed, of such magnitude that the circulation, thereby produced, will be equivalent to the circulation destroyed on the rest of the surface. Hence it is that the circulation and consequently the lift of an airfoil is always somewhat smaller than that computed with the aid of the theory of the ideal fluid under the assumption that the single separation point moves to the trailing edge and that there is therefore no flow around the trailing edge.

From the above explanation, it follows that only a slight increase in the circulation around an airfoil is possible at normal angles of attack. If we imagine, with an airfoil in the region of normal angles of attack, the artificial production of a stronger circulation than would be automatically developed, we would soon reach the point where a flow around the trailing edge would take the opposite direction and thus, at great flow velocities, strong vortices would be generated at the trailing edge, which would destroy the artificially produced circulation. Mr. Wieland's results therefore correspond perfectly to the expectations, since they require no great increase in the lift at normal angles of attack.

The conditions are quite different, however, at large angles of attack, which increase the velocity on the suction side. Then, due to the viscosity vortices are produced and carried along by the body. Hence they change, to a certain extent, the whole profile shape and consequently the character of the flow. Thus it happens that, with increasing angle of attack, a point is reached where any further increase of the circulation, and consequently of the lift, by increasing the angle of attack, is no longer possible, because the trailing edge of the airfoil has assumed an entirely different form and has become ineffective as regards the development of the circulation.

If, at such large angles of attack, care is taken that no friction can develop on the suction side of the airfoil, then, in accordance with the above considerations, a considerably greater circulation will be produced. The effect of the fluid friction on the suction side of the airfoil can be avoided in various ways as, for example, by removing the vortex layers by suction. This method has already been thoroughly investigated at Göttingen (N.A.C.A. Technical Memorandums Nos. 374 and 395).

Another possibility, however, is to set the surface of the body in motion in the direction of the flow. Experiments in this direction have already been made and indeed, through the combination of rotary cylinders with airfoils, probably suggested by the Göttingen experiments with rotary cylinders (N.A.C.A. Technical Memorandums Nos. 307, 354, 382, and 424). There is a fundamental difference, however, between the rotary cylinder alone and its combinations with airfoils. While in the former case the circulation is produced only by the friction on the surface of the cylinder and the direction of the air flow is indifferent, due to the rotational symmetry, in the latter case the circulation is affected by the airfoils. In this case, if it is desired to assist the circulation or to produce a certain kind of circulation by a correspondingly high rotational speed, care must be taken that, by employing the corresponding angle of attack, the desired circulation can actually be developed and not be destroyed by the airfoil. This precaution was neglected in a series of experiments performed in another country and, in consequence, apparently only negative results were obtained.

It might be of interest that, ten years ago, Föttinger proposed to obtain the same effect by means of an airfoil consisting of a thick cylinder for the leading edge and a thin cylinder for the trailing edge, the cylinders being rotated by an endless belt passing over them both.*

It is logical, however, to replace this belt with a fluid layer, blown at such a velocity that, after being retarded by the surface of the airfoil, it will still have sufficient velocity not to be drawn along by the airfoil, but to continue to

*Föttinger, "Neue Grundlagen für die experimentelle und theoretische Behandlung des Propellerproblems," A lecture before the "Schiffbautechnische Gesellschaft" at their 19th regular meeting in 1917.

flow with the surrounding fluid. The process can be represented as follows. The ejected air mingles with the retarded air molecules near the surface and imparts to them some of its own momentum. If the mixture is thus given sufficient velocity to penetrate the region of higher pressure behind the airfoil, there is no further cause for the separation of the flow. The process is therefore just the same as on the slotted wings of Lachmann and Handley Page.

A thorough investigation was undertaken at the D.V.L. in the spring of 1925. On account of the burning of the wind tunnel, it could not be finished until the spring of 1927 brought the opportunity to do so in the wind tunnel of the Zeppelin Company at Friederickshafen. The investigation was limited chiefly to the region of high angles of attack since, as explained above, it is only in this region that any considerable change in the character of the flow can be expected from such artificial aids. The investigation was intrusted to Miss Kober.

The airfoil was a used model of 1 m (39.37 in.) span and 20 cm (7.87 in.) chord, hence with an aspect ratio of 5. Its profile corresponded to the Göttingen profile 422. The introduction of an air slot, extending the whole length of the model somewhat behind the thickest part of the airfoil, only slightly altered its profile. The slot, through which compressed air was blown, was formed by two pieces of sheet steel connected by screws at intervals of about 5 cm (2 in.). It was intended to regulate the width of the slot by means of these screws. It was found, however, that, due to the elastic deformation of the thin sheets, it was not possible to obtain a uniform width of the slot. The compressed air was taken from compressed-air cylinders. Its pressure was first reduced by a reduction valve to the pressure required for the experiment. The air was then led into the airfoil. The experimental arrangement is shown in Fig. 1. Much more compressed air was required than was originally supposed. Hence all the delivery pipes were much too small. The pressure was measured at the exit from the cylinder. Considerable losses occurred in the delivery pipes, owing to their weak construction, so that no reserve energy could be obtained. This experiment, therefore, is to be regarded only as a preliminary one, which showed that the expected phenomenon actually occurred. The requisite pressures, with suitably dimensioned delivery pipes, would probably be much smaller than with the pipes actually used.

Figs. 2-3 show that, qualitatively, the expected result was really obtained. In Fig. 2, where an ordinary airfoil had a large angle of attack, the threads on the suction side show thick vortical layers, while the threads in Fig. 3, where compressed air was used, indicate a smooth flow.

Fig. 4 shows the c_a values of the airfoil model with delivery tube and also (dash line) the c_a values of the Göttingen profile 422, both obtained without using compressed air.

Fig. 5 shows the c_a values plotted against the angle of attack, first for the airfoil without the release of compressed air, and also the lift values at large angles of attack, when compressed air was released at 2, 3, and 4 atmospheres, respectively. The reaction of the compressed air on the airfoil was likewise determined at a pressure of 4 atm. For better comparison, this force and also the lift were divided by the circulation Fq (F = wing area; q = dynamic pressure in wind tunnel) and plotted as a coefficient. In this connection, it is to be noted that the reaction force is independent of the velocity in the tunnel and that therefore this coefficient is correct only for the velocity of 30 m (98.42 ft.) per second, which was taken as the basis for the evaluation. At higher velocities, the ratio of the reaction force to the total lift is smaller, and at lower velocities it is correspondingly greater.

The plotted curves show that the expected effect actually occurred and that the maximum lift was increased in proportion to the energy of the compressed air. The maximum c_a was 3.35 at an angle of approximately 30° while the $c_{a\ max}$ of the same airfoil without the compressed air was only 1.55 and was reached at an angle of attack of about 20°. The above-described device was patented by Professor Baumann of Stuttgart. This fact first became known to the writer through the publication of the patent in the "Zeitschrift für Flugtechnik und Motorluftschiffahrt" of December 28, 1926, when the investigation had already been begun.

Regarding any practical applicability, no final conclusion can yet be reached on the basis of this investigation. It would be necessary to determine the added energy accurately and to test various arrangements of the slot. It does not appear impossible, however, that some practical application may be successfully made.

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

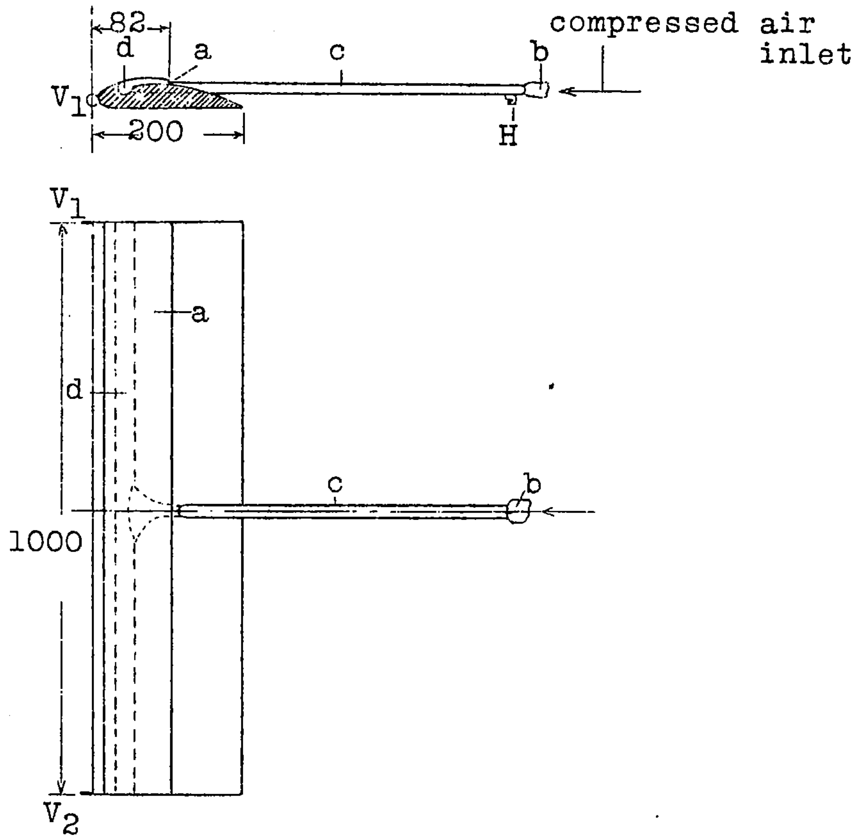

Fig.1 Experimental arrangement.

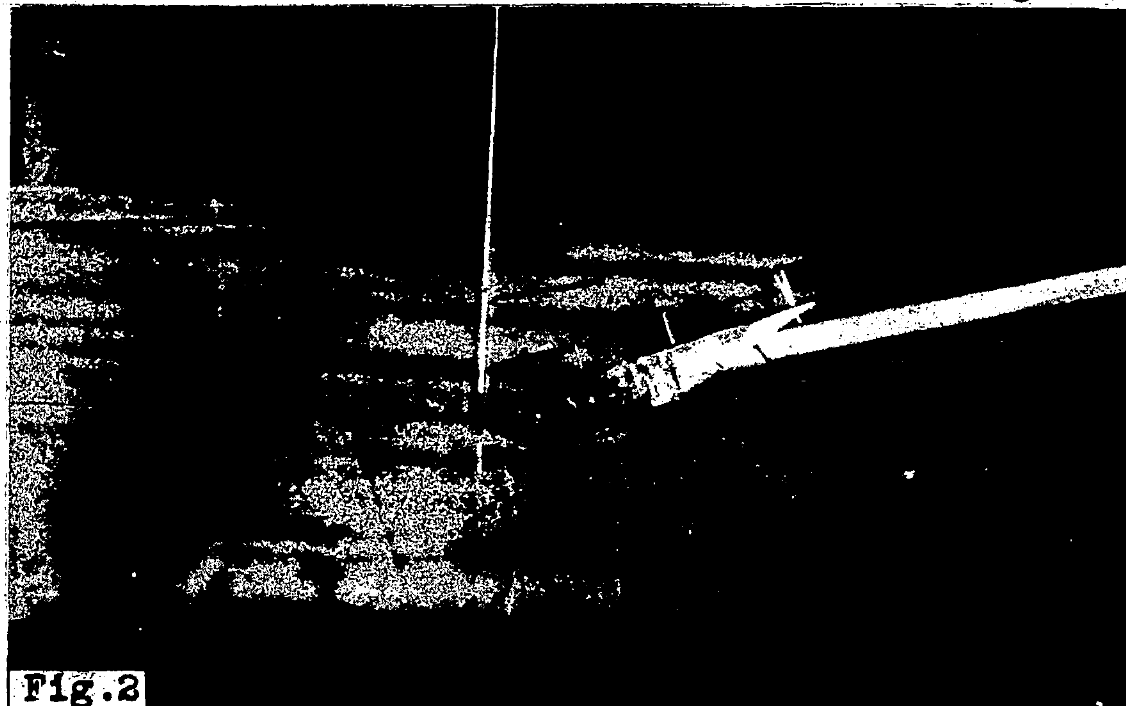

Fig.2

Flow at large angles of attack with an ordinary airfoil. The threads on the lower side show thick vortex layers.

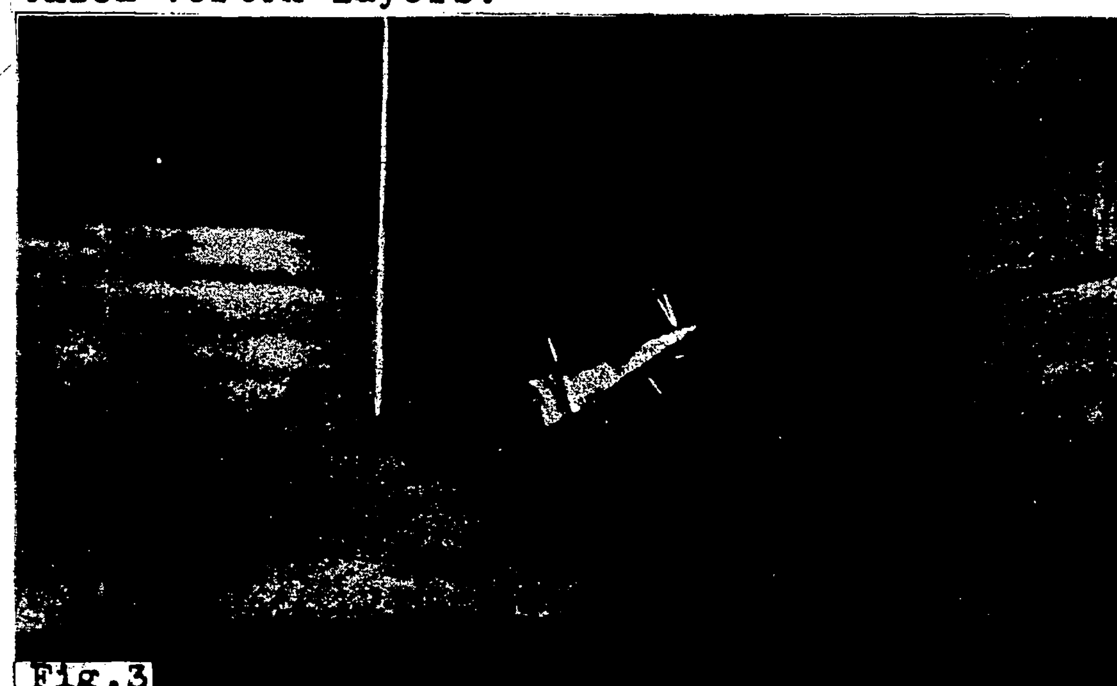

Fig.3

Flow under same conditions as in Fig.2 with outflowing compressed air. The threads show a smooth flow.

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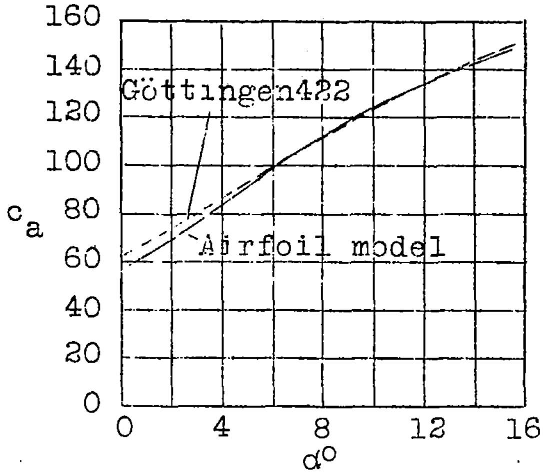

Fig.4 Comparison with Göttingen result.

I Without comp.air(airfoil similar to Göttingen 422
II With 4 atm.comp.air
III " 3 " " "
IV " 2 " " "
V Effect of reaction of out-flowing comp.air on airfoil (4atm.)

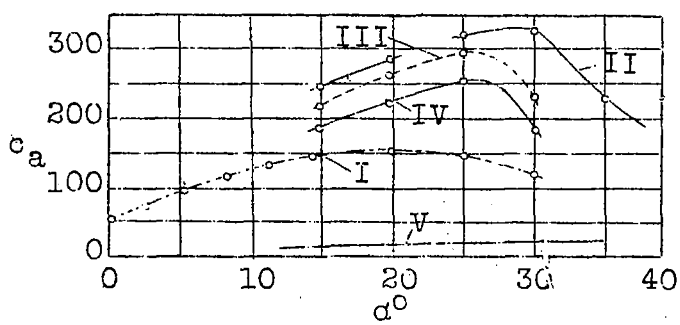

Fig.5 Results with compressed air.